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What is the wind speed accuracy of SODARs?

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What is the wind speed accuracy of SODARs?

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Overview

The push to show that LIDAR/SODAR winds and mast winds are equivalent

Typically correlations R^2 are given

What does R^2 tell you about the instrument?

Is this the best performance measure?

Comparing 2 remote sensing instruments

How transferable is an R^2 indicator from site to site?

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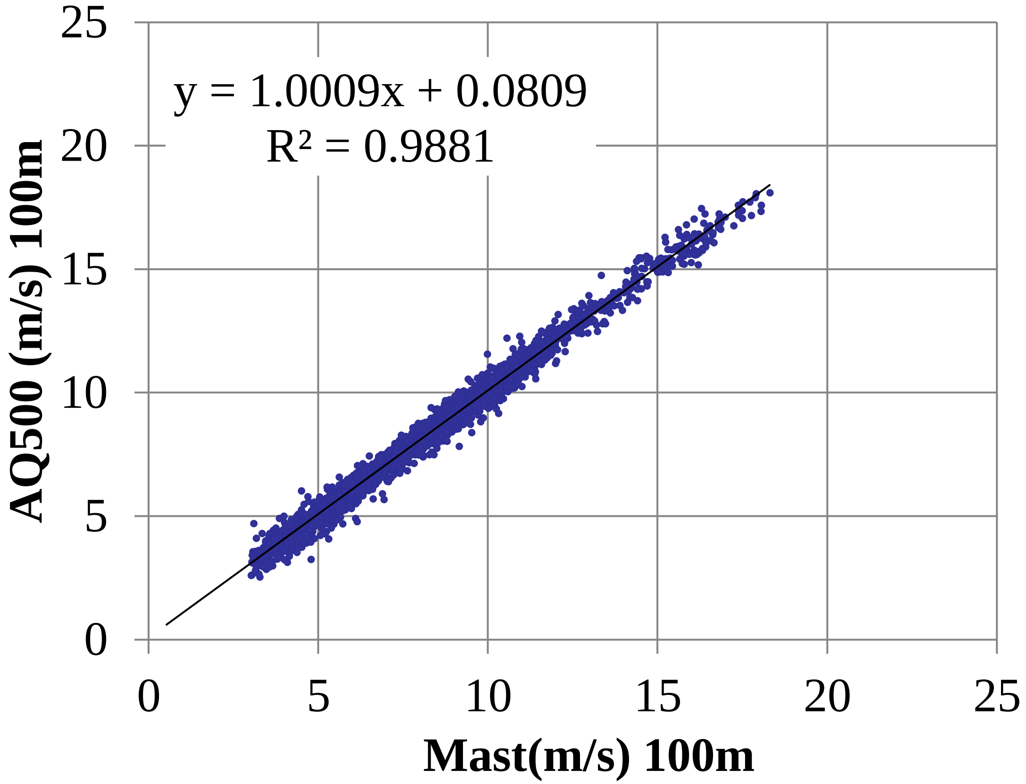
AQ500 test by ECN March 2010



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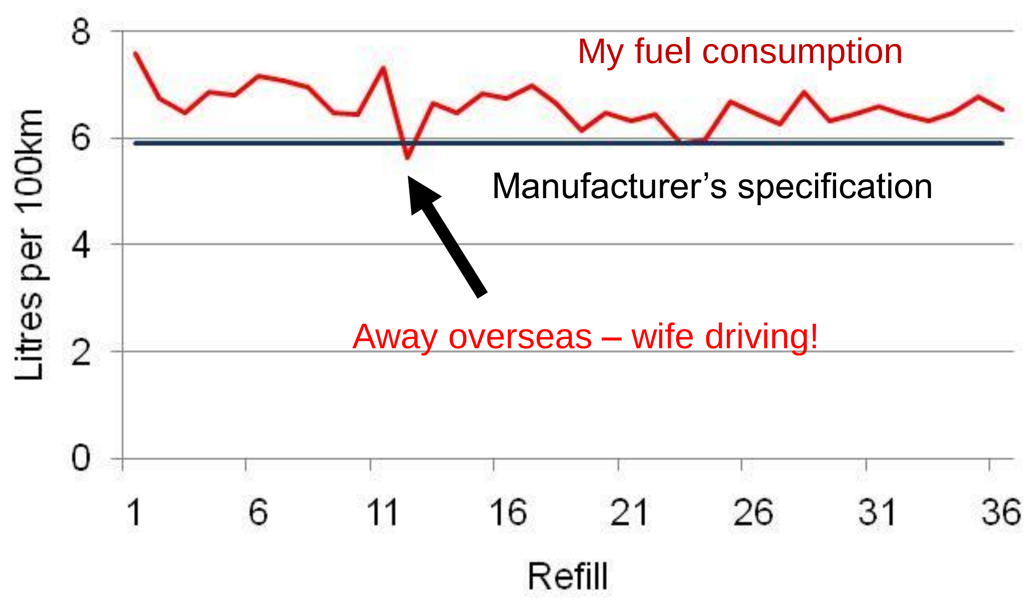
Real vs Ideal: my car



Manufacturer's fuel figure:

flat, dry, racetrack, moderate temperatures, constant optimum speed, optimum tyre inflation, moderate temperatures, overcast, new oil, new car, etc

My fuel figure:

city driving, hills, stop-start, accelerate, air-conditioning, attached trailer, 6 months since service, non-optimum tyre pressure, etc

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Ideal "Lab" performance

Remote sensing with LIDAR (laser) or SODAR (sound) measures wind within a *volume*

Direct measurement (cup anemometer, sonic anemometer) measures wind at a *point*

The two methods *only agree in very special circumstances* (when the properties within the remote sensing volume are uniform over that volume)

Most remote-sensing vs mast inter-comparisons are limited to

very flat terrain, no ground cover variation, no convective heating, simple wind shear, low turbulence, no fog, no low cloud, no rain

You will almost never reproduce these conditions

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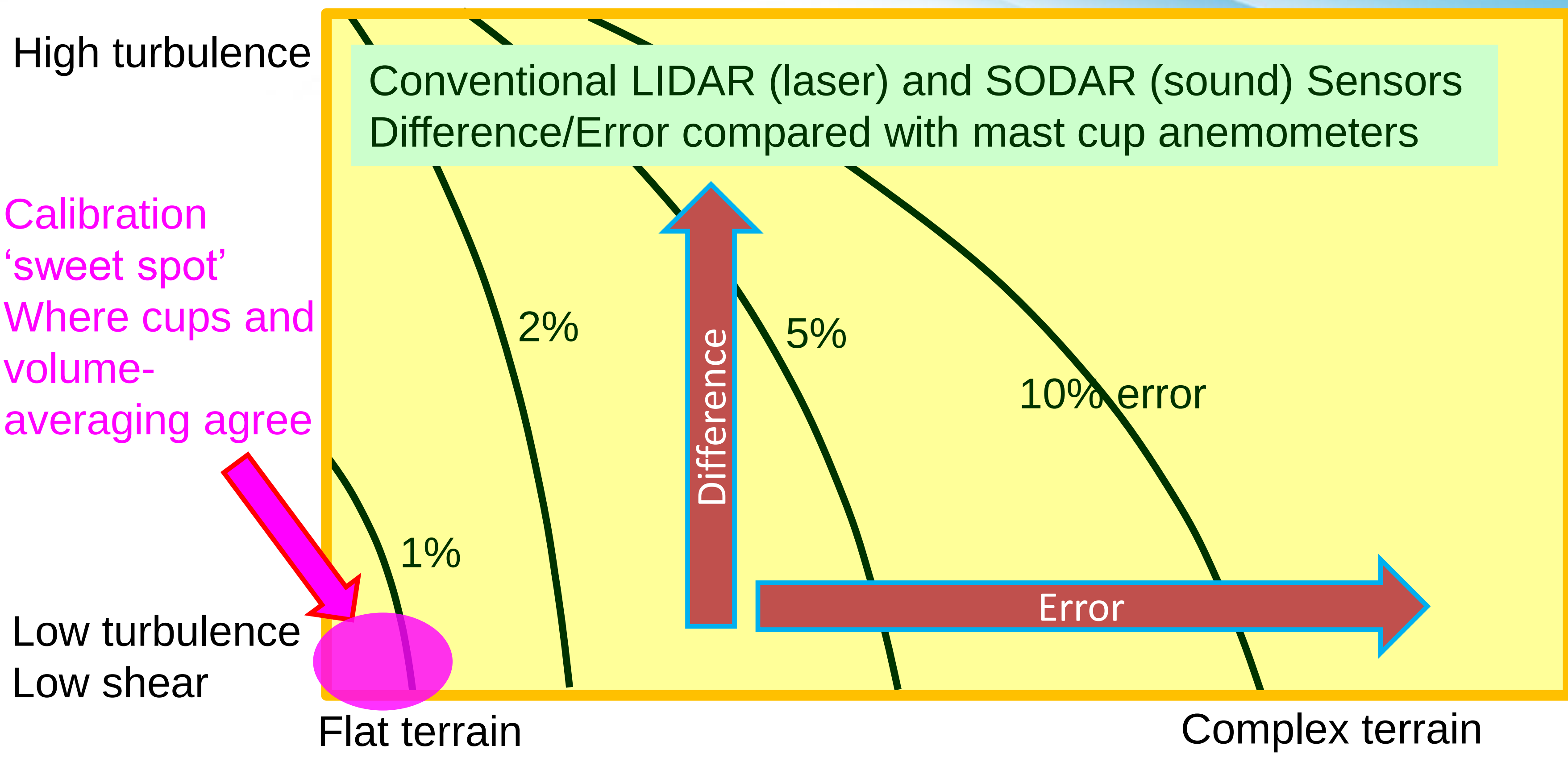
Conceptual diagram



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Motivation: 2 Questions

What do R^2 values mean in terms of predicting differences in measured wind speed?

Differences between cup anemometers and remote sensing instruments are the essence of whether remote sensing gives ‘bankable’ data

What quality of wind measurements can be expected from LIDARs or SODARs in a typical installation?

Intercomparisons are typically under very restricted and controlled conditions, quite unlike those typically encountered at wind farm sites

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Correlation R^2

The n^{th} measurement pair is $U_{r,n}$ and $U_{m,n}$ for remote and mast instruments

$$R^2 = 1 - \frac{\sum_{n=1}^{N}\left(U_{r,n} - aU_{m,n}\right)^2}{\sum_{n=1}^{N}\left(U_{r,n} - \overline{U}_{r,n}\right)^2} \approx 1 - \frac{\left(\frac{\Delta U_{rms}}{U_{av}}\right)^2}{\left(\frac{\sigma_U}{U_{av}}\right)^2}$$

U_{av} and σ_U^2 are the mean and variance of the wind speed over the measurement intercomparison period

ΔU_{rms} is the rms difference between mast and remote measured wind speeds

σ_U arises from diurnal and synoptic variations in wind speed and should not be confused with the short-term fluctuations due to turbulence

σ_U / U_{av} depends on the shape parameter of the Weibull distribution (i.e. on the wind conditions during the intercomparison)

R^2 is NOT solely a property of the instrument

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Wind Regime σ_U / U_{av}

$$R^2 \approx 1 - \frac{\left(\frac{\Delta U_{rms}}{U_{av}}\right)^2}{\left(\frac{\sigma_U}{U_{av}}\right)^2}$$

σ_U / U_{av} depends on the probability distribution of wind at the comparison site e.g. If R^2 = 0.99 when Weibull shape factor k= 2, then R^2 = 0.95 at k = 5, if only k is changed.

A better measure is

$$\left(\frac{\sigma_U}{U_{av}}\right)^2 \left(1 - R^2\right) \approx \left(\frac{\Delta U_{rms}}{U_{av}}\right)^2$$

or

$$B^2 = 1 - 3.66 \left(\frac{\sigma_U}{U_{av}}\right)^2 \left(1 - R^2\right)$$

Where 3.66 is the value of $(\sigma_U / U_{av})^{-2}$ for Weibull shape k = 2.

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Where does ΔU_{rms} come from?

$$R^2 \approx 1 - \frac{\left(\dfrac{\Delta U_{rms}}{U_{av}}\right)^2}{\left(\dfrac{\sigma_U}{U_{av}}\right)^2}$$

ΔU_{rms} arises from

- The difference between scalar (cup-type) and vector (remote-type) measurements
- Remote sensing sampling over spatially distributed volumes
- Remote sensing sampling for each wind estimate spread over time
- Spatial separation between the remote sensing volumes and the mast sensor
- Remote sensing in the presence of background noise.

Ultimately, if the site is uniform, turbulence intensity is very low, background noise is minimal, and wind speeds are widely distributed, then a very high R^2 should be achieved by any good quality SODAR or LIDAR remote sensing instrument

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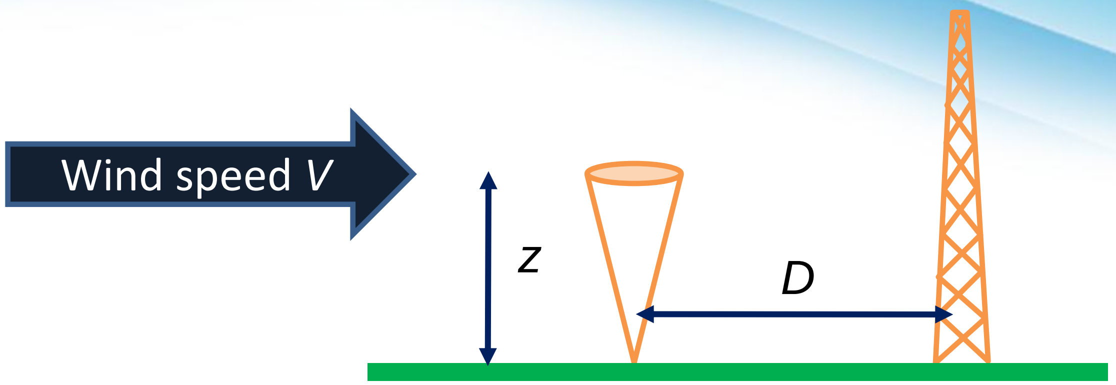
Comparison with mast cup anemometers



What is the relationship between winds measured at a mast, and winds measured distance D away?

For constant, spatially uniform, wind, they will be the same

For fluctuations faster than the time D/V, there will be a loss of correlation

SODARs are generally placed about 100m from a mast. This inter-comparison design introduces a decrease in R^2 compared with a LIDAR close to the mast

This decreased R^2 does not represent an error !

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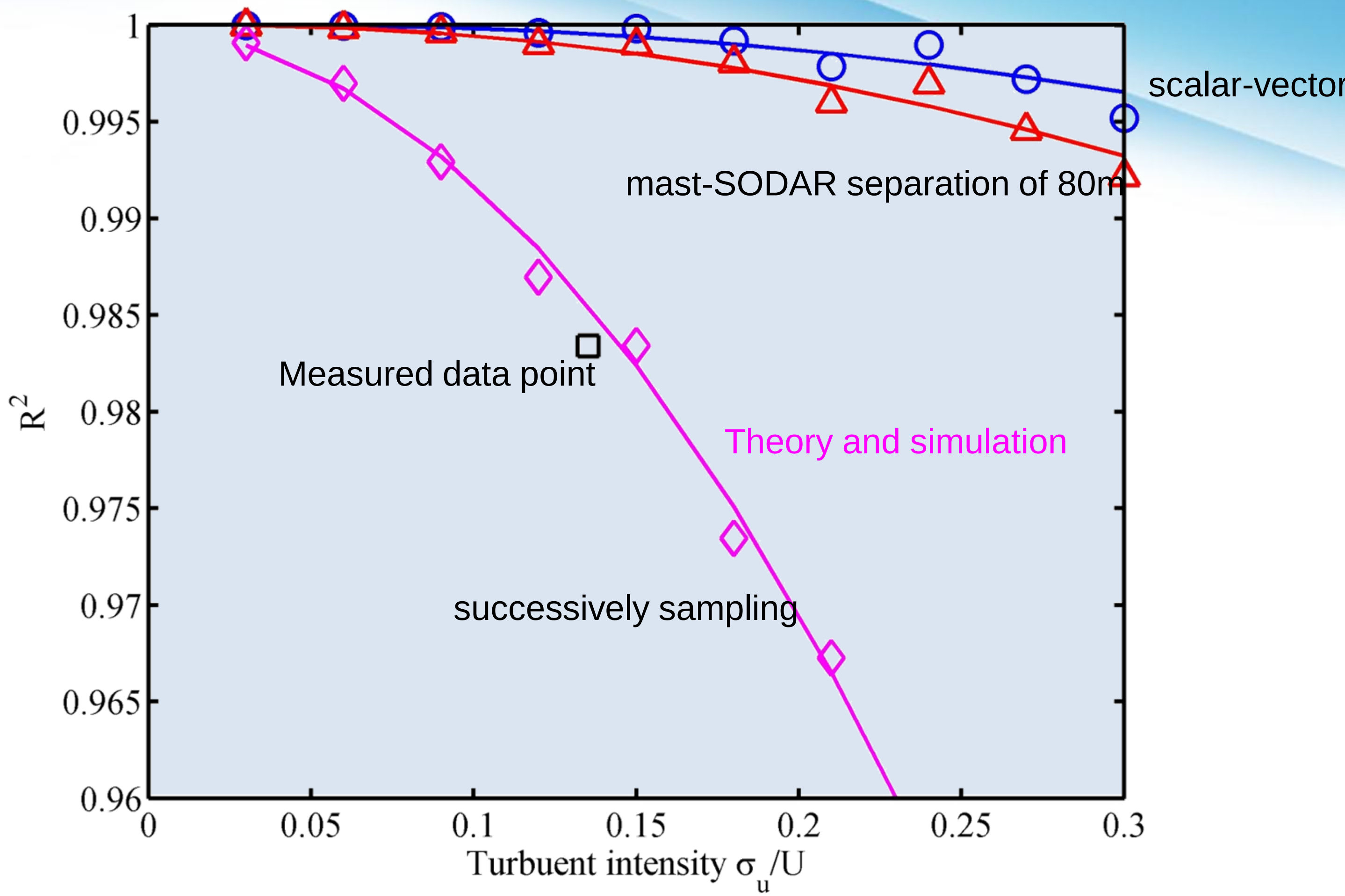
Types of mast-remote difference



The largest error arises from the separated sampling volumes, when turbulence is strong

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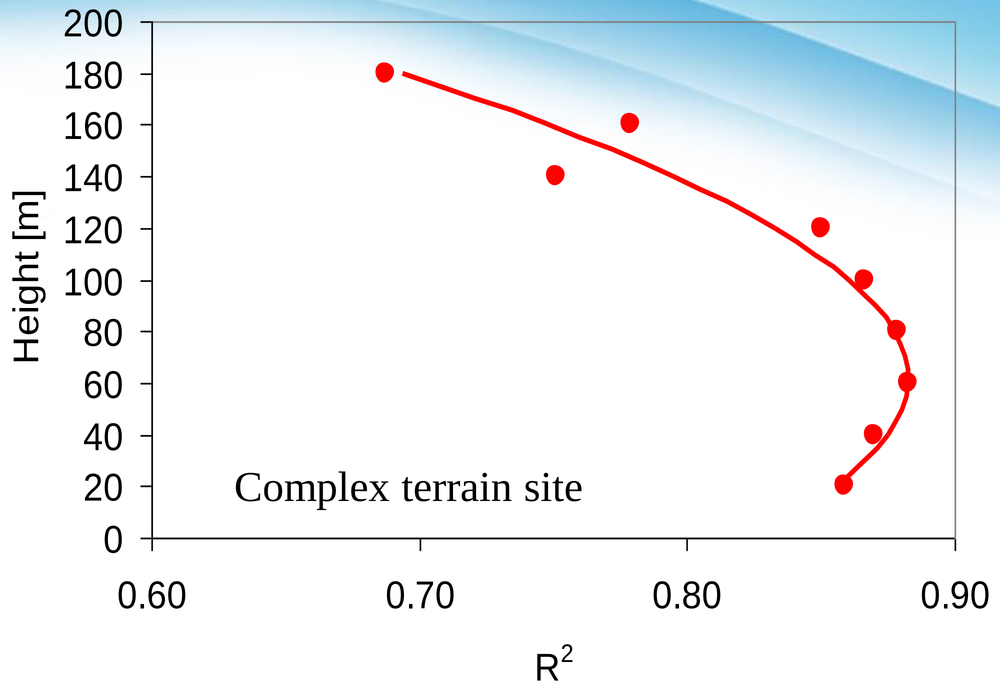
Spatial coherence of wind affects SODAR winds



Plot of measured and modelled correlation between winds measured by different beam combinations *on the same 5-beam SODAR* (at a complex site)

At 60m, the time taken for air to travel from one beam to another (at the wind speed during these measurements) is equal to the time between acoustic pulses

The shape of this curve is a measure of the spatial correlation for wind.

Behrens P, Bradley S, Wiens T. A Multisodar Approach to Wind Profiling. *J. Atmos Ocean. Tech*. 2010; **27**: 1165-1174.

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Comparing Two Remote Sensing Instruments

Usual method: Show intercomparisons for each vs mast

U_1 vs U_m and U_2 vs U_m

But

$$(\Delta U_{1,2\ rms})^2 = (\Delta U_{1,m\ rms})^2 - 2 \langle \Delta U_{1,m}\ \Delta U_{2,m} \rangle + (\Delta U_{2,m\ rms})^2$$

So R^2 between the two remote sensing instruments can vary widely depending on the correlation term $\langle \Delta U_{1,m}\ \Delta U_{2,m} \rangle$.

If $\Delta U_{1,m} = \Delta U_{2,m}$, the two instruments are the same and $R_{1,2}{}^2 = 1$.

If $\Delta U_{1,m} = -\Delta U_{2,m}$, then $1 - R_{1,2}{}^2 = 4(1 - R_{1,m}{}^2)$

Comparisons need to be instrument-to-instrument

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‘Q’ of R^2

For tuned systems, a high ‘Q’ means that the gain falls rapidly for small changes in tuning parameters.

More and more effort goes into finding optimum filters for remote sensing instruments so that high R^2 values are obtained when compared with mast instruments at an ideal site. This means the R^2 values are becoming high-Q.

Moving a high-R^2 system from one site to another, or using slightly different software, is likely to give a big change in R^2.

The lower R^2 systems, if less ‘tuned’, are likely to give more consistent rms variations compared with masts at a range of sites.

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Summary

Ground-based remote sensing is the next standard for wind measurement in support of wind energy

However, most comparisons with mast-mounted instruments are in very idealised conditions, and not representative of actual operational environments.

This is particularly true of reported LIDAR results

R^2 values depend **strongly** on the wind regime, the experimental setup, and on the data filtering

Comparing two remote sensing instruments with a mast installation does not tell you how well the two remote instruments agree

More highly tuned data filtering means the high R^2 values obtained are more likely to be non-representative

There is much to think about in providing a statistically robust and traceably standard for remote sensing of winds.

Bradley S. and Mikkelsen T. SODAR Remote Sensing. International Sustainable Energy Review, 5**,** June 2011, 38-41

Mikkelsen T. and Bradley S.. LIDAR Remote Sensing. International Sustainable Energy Review, Volume 5, 2011

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